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# Into the Microbial Realm: A Comprehensive Study of Microbial Enhanced Oil Recovery Technique

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***Abstract:*** **The global demand for oil and natural gas continues to serve as a pivotal catalyst for the advancement of industries and the growth of economies. Considering the challenges faced by conventional extraction methods, it becomes essential to explore innovative approaches. Conventional recovery methods often leave a significant portion of residual oil in the reservoirs. Enhanced Oil Recovery (EOR) emerges as a crucial solution to maximize the hydrocarbon extraction efficiency. Despite the advantages provided by EOR, it comes with a handful of challenges and environmental concerns. Microbial Enhanced Oil Recovery (MEOR) has emerged as a viable and environmentally sustainable technique for oil recovery in the realm of EOR. It involves using microorganisms and their bioproducts to enhance the oil recovery. The microorganisms interact with the oil, causing alteration of its properties like viscosity, interfacial tension etc. MEOR holds the potential to revolutionize the oil industry by improving hydrocarbon extraction efficiency, reducing environmental impact, and mitigating the decline of mature oil fields. This paper aims to provide a comprehensive overview on the key aspects of MEOR. As the energy industry seeks greener alternatives, MEOR stands out as a transformative approach with the potential to revolutionize oil recovery practices.**

***Keywords:*** MEOR, EOR, Hydrocarbons, viscosity, interfacial tension.

## I. INTRODUCTION:

The recovery of oil is a critical aspect for petroleum industry, ensuring the recovery of the maximum amount of oil possible from the reservoirs located in the subsurface to meet the increasing global energy demands. Three methods are employed for oil recovery: primary recovery, secondary recovery and tertiary recovery.

The primary recovery process refers to the recovery of oil from the reservoir by utilizing the natural energy of the reservoir as the primary source to displace the oil. These natural energy sources are solution gas drive, gas cap drive, water drive, gravity drainage and rock & fluid expansion drive. Primary recovery typically recovers only about 5-10% of the total oil volume in the reservoir. When the natural reservoir energy has been depleted, it becomes imperative to supplement the natural energy by means of an external source. This is usually accomplished by the injection of fluids, either a natural gas or water. The use of this injection scheme is called a secondary recovery process. Water flooding is the most common secondary recovery process. It can recover up to 40% of the total oil volume in the reservoir. Tertiary recovery, simply called Enhanced Oil Recovery (EOR) involves the use of advanced and complex technologies to recover additional oil after primary and secondary methods have been exhausted. According to the most recent global reserves data, reservoirs across the world will still contain approximately 2 trillion barrels of conventional oil and 5 trillion barrels of heavy oil once conventional extraction techniques have been fully utilized. Hence, efforts are being made to explore techniques for EOR in order to extract more oil from existing and abandoned oil fields.

Enhanced Oil Recovery (EOR) techniques may be divided into thermal methods, chemical and gas injection methods. Thermal method involves the injection of thermal energy or in-situ heat generation in the reservoir to improve the recovery of oil. Chemical methods involves injection of certain chemicals such as polymers, surfactants or alkaline agents that possess a potential to either alter the properties of the reservoir fluids or enhance the recovery mechanisms. The primary approach in miscible injection methods is to inject gases that have miscibility with the oil or that lead to miscibility in the reservoir by modifying its composition. These methods often face challenges, including high cost and environmental concerns which led to the development of advanced EOR methods. One such method was Microbial Enhanced Oil Recovery (MEOR). It is seen as a highly promising solution in the field of tertiary recovery. The idea of using microorganisms for the recovery of oil was first suggested by Beckman back in 1926 [14]. However, in 1946, C.E. ZoBell took the initiative to perform empirical experiments to validate Beckman's theory [16]. The first MEOR field test was conducted in the Lisbon field, Union County, Arkansas, in

 

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1954. Since then, the MEOR process has been validated by numerous studies and proven to be effective in field tests.
MEOR presents several benefits in comparison to conventional EOR techniques. It is an environmental friendly technique that diminishes the necessity for aggressive chemicals and energy-intensive processes. Moreover, MEOR is inexpensive, especially as compared to the thermal methods. The use of microorganisms can also extend the lifespan of mature oil fields, thereby enhancing their economic feasibility.
As technology progresses and our understanding of microbial processes becomes more profound, it is anticipated that MEOR will play an increasingly important role in addressing the world's escalating energy demands while mitigating the environments impacts of oil extraction.

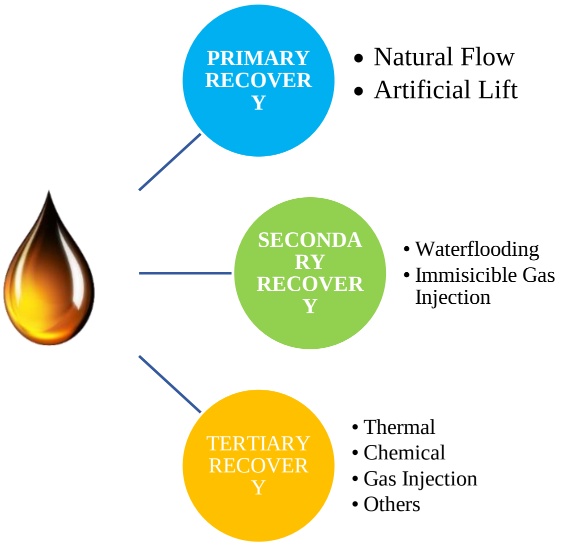


Fig. Methods of Oil Recovery

## II. MICROBIAL ENHANCED OIL RECOVERY:

Microbial Enhanced Oil Recovery (MEOR) is a tertiary method of oil recovery which involves using microorganisms and their bioproducts to enhance the oil recovery. The microorganisms interact with the oil, causing alteration of its properties. Researchers exclusively utilize bacteria as microorganisms for MEOR owing to their minuscule size, their ability to generate valuable metabolic compounds such as gases, acids, solvents, biosurfactants, biopolymers, biomass etc. The ability of these microorganisms to withstand extreme conditions similar to those encountered in subsurface formations in terms of pressure, temperature, pH, salinity has heightened their appeal for utilization in EOR purposes. MEOR is said to be capable of producing up to 50% of the residual oil. The average size of bacterial cells varies from 0.5 to 5.0 m, enabling them to more easily permeate the porous media of the reservoir. It has been determined that in the case of MEOR processes involving the injection of bacteria into the reservoir, it is imperative for the microorganisms to possess specific characteristics. Specifically, these microorganisms must exhibit a small size, a spherical shape, and a size that is less than 20% of the dimensions of the pore throat in the formation. Bacillus and Clostridium species are commonly utilized for MEOR because of their capacity to produce quiescent, resilient endospores that can withstand adverse environmental conditions, while also producing useful bio products for MEOR.

## III. MECHANISM OF MEOR:

During the process of MEOR, the different components are mixed together at the surface facilities and subsequently introduced into the oil reservoir. Inside the reservoir, MEOR-bacteria are transported via the injected water and accumulate within porous regions located at the interfaces of oil/rock as well as oil/water. These bacteria interact with the oil to produce metabolic products such as surfactants, acids, solvents and carbon dioxide. The mechanisms of MEOR based on microbial metabolic products can be classified into the following parts:

- Surfactants reduce the interfacial tension between oil and water, helping to mobilize the oil.
- Acids help in the dissolution of minerals (i.e., clays, carbonates, etc.) contained in the formation rock. Rock dissolution increases the porosity and permeability of the reservoir.
- Solvents and biogas lowers the oil viscosity that facilitates oil displacement through the porous media.
- Furthermore, biopolymers produced by microorganism acts a viscosifiers. They increase the viscosity of the injected water, improving its ability to sweep through the reservoir and displace oil from rock surfaces. The increased viscosity helps push trapped oil towards wellbore.
- Gases such as methane and carbon dioxide contribute to the expansion of reservoir fluids, creating additional pressure that aids in displacing oil towards wellbore.

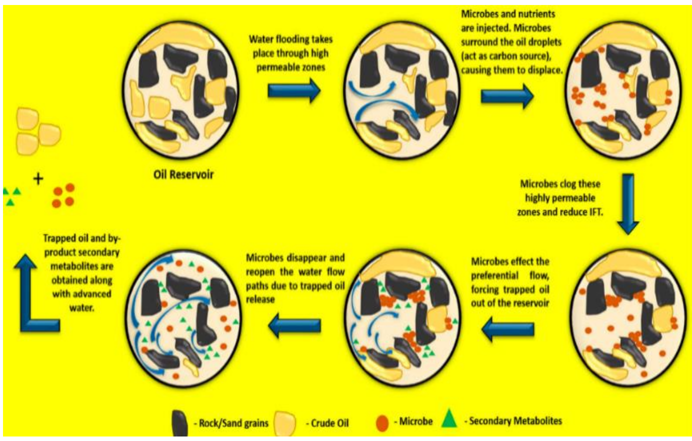


Fig. MEOR Mechanism [4]

## IV. MICROBIAL CANDIDATE FOR MEOR:

In MEOR, bacteria are categorized based on their oxygen requirements: aerobes, which thrive in oxygen-rich environments; strictly anaerobes, sensitive to even low oxygen levels and found in deep oil reservoirs; and facultative microbes, capable of growing in varying oxygen concentrations. Lazar [20] identified four key sources for isolating MEOR candidate bacteria: formation waters, sediments from water purification plants, biogas sludge, and effluents from sugar refineries. Oil-contaminated soil and hot water streams are also potential sources.

MEOR processes are cost-intensive, with nutrient expenses being significant. Fermentation mediums can constitute up to 30% of the cost. Bacteria require carbon, nitrogen, and phosphorous sources for growth, often in the ratio of C, 100: N, 10: P, 1. Nutrient types and concentrations play a crucial role in determining the bio products produced. Cheap raw materials like molasses and cheese whey, rich in essential components, are commonly used. Joshi [19] proposed utilizing cheese whey for bio surfactant production, and molasses, a by-product of sugar production, is valued for its low cost and vitamin content. Some microbes use oil as a carbon source, beneficial for heavy oil production, as seen in experiments using kerosene. It is essential to understand the nutritional preferences of microbes to maximize desired metabolite production, ensuring cost-effective supplies.

## V. PROCESSES OF MEOR:

Two distinct processes are used for MEOR, depending on the site of bioproducts production, namely in-situ process and ex-situ process.

- In-situ Process: This process refers to the production of microbial bioproducts directly within the reservoir to stimulate specific biochemical reactions that improve oil recovery. In case of the in-situ process, where exogenous microbes are introduced into the reservoir, it is essential to conduct compatibility investigations to determine the interaction between the injected microbes and the native microbes, nutrients, oil, and rock. The success of an in-situ MEOR process is determined by the selection of the appropriate reservoir, the proper choice of potential bacterial species, the viability of these bacteria within the subsurface conditions, the quantity of metabolites produced, and their consequential impact on the liberation of residual oil. Additionally, economic considerations play a significant role in determining the success of this MEOR process.
- Ex-situ Process: This process involves the production of the bioproducts at the surface outside the reservoir before their introduction. In this case, commercial size bio-reactors are needed to scale-up the production of the desired metabolite for field applications. In ex situ process, where exogenous microbes are introduced into the reservoir, it is important to conduct capability studies to determine the interaction of the injected microbes with the indigenous ones

## VI. MICROBIAL BIOPRODUCTS:

Microorganisms produce a variety of metabolic products that are potentially useful for oil recovery. These includes:

### A. Biosurfactants

These are amphipathic molecules with both hydrophilic and hydrophobic parts which are produced by variety of microorganism. They are capable of reducing the surface and interfacial tension by accumulating at the interface of immiscible fluids and increasing the solubility and mobility of hydrophobic or insoluble organic compounds. In recent times, there has been a surge in interest in biosurfactants owing to their minimal toxic effects, high biodegradability and cost efficiency. There are five major types of biosurfactants namely lipopeptides, phospholipids, glycolipids (which include rhamolipids, trehalose lipids and sophorolipids), fatty acids and neutral lipids.

### B. Biopolymers

These are polysaccharides which are secreted by many strains of bacteria mainly to protect them against temporary desiccation and predation as well as to assist in adhesion to surfaces [6, 7]. This mechanism of biopolymers involves selective plugging of the high permeability zones to modify the permeability of the oil reservoir to the floodwater, to effectively reach the oil-rich pores [6]. Another important process of biopolymers is their potential as mobility control agents by increasing the viscosity of the displacing water hence improving mobility ratio and sweep efficiency [10].

### C. Biosolvents

Sometimes, the microorganisms have the ability to generate solvents as one of their metabolites. These solvents consist of ethanol, acetone, and butanol. They can assist in the reduction of oil viscosity and act as a co-surfactant to decrease the interfacial tension between oil and water.

### D. Biomass

The mechanism of the microbial biomass in MEOR involves selective plugging of high permeability zones where the microbial cell will grow at the layer pore throats restricting the undesirable water flow through the pores [11]. This will necessitate the diversion of the displacing water towards the smaller pores as a result of which the un-swept oil will be displaced, thereby increasing the oil recovery.

### E. Bioacids

Certain bacteria have the capacity to generate acids, such as lactic acid, acetic acid, and butyric acid, when exposed to particular nutrients. These acids can be useful in carbonate reservoirs or a sandstone formation sandwiched by carbonates, since some of these cause dissolution of the carbonate rock and hence improve its porosity and permeability [12].

 

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F. Biogases

Bacteria can ferment carbohydrates to produce gases such as carbon dioxide, hydrogen and methane gas. These gases can be utilized in optimizing oil recovery by exploring the mechanisms of reservoir re-pressurization and reducing heavy oil viscosity. The gases can contribute to the pressure build-up in pressure depleted reservoir [7]. Furthermore, these gases can contribute to the reduction in oil viscosity by dissolving into the oil, increasing sweep efficiency. Certain bacteria have been reported to possess the ability to generate gas, including Clostridium, Desulfovibrio, Pseudomonas, and specific methanogens.

Table 1- Microbial bioproducts and their applications in MEOR [18]

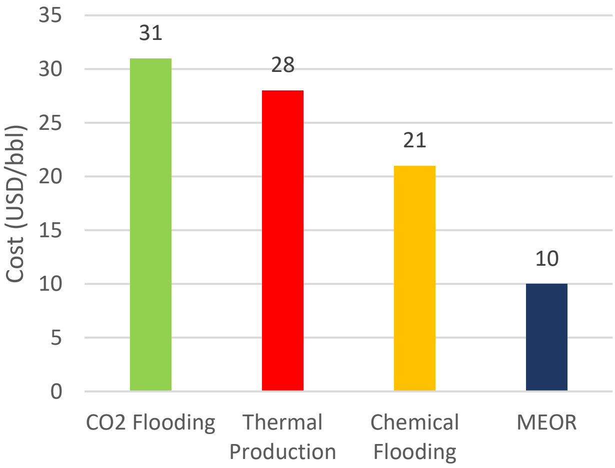
| **Microbial Products** | **Microorganisms** | **Application in MEOR** |
|---|---|---|
| Biomass | *Biomass Bacillus, Leuconostoc, Xanthomonas* | Selective plugging and wettability alteration |
| Biosurfactants | *Acinetobacter, Arthrobacter, Bacillus, Pseudomonas* | Emulsification and de-emulsification through reduction of IFT |
| Biopolymers | *Bacillus, Brevibacterium, Leuconostoc, Xanthomonas* | Injectivity profile and viscosity modification, selective plugging |
| Bio-solvents | *Clostridium, Zymomonas, Klebsiella* | Rock dissolution for better permeability, oil viscosity reduction |
| Bio-acids | *Clostridium, Enterobacter, Mixed acidogens* | Permeability increase, emulsification |
| Biogases | *Clostridium, Enterobacter Methanobacterium* | Increased pressure, oil swelling, IFT and viscosity reduction |

## VII. ADVANTAGES OF MEOR:

The various advantages associated with MEOR are listed below:

- MEOR is environmentally friendly, because microbial products are biodegradable.
- MEOR is an inexpensive process as compared to other EOR processes. The employment of microorganisms can reduce the need for expensive chemicals and equipment.
- Microorganisms utilized in the MEOR possess the capacity to alter the characteristics of both the reservoir rock and fluid, thus facilitating a more efficient flow of oil through the reservoir. This can lead to increased oil recovery efficiency, allowing for the extraction of more oil from the reservoir.
- MEOR has the potential to improve the sweep efficiency of injected fluids in the reservoir, which helps in displacing more oil and recovering a higher proportion of the original oil in place.
- More efficient compared to other EOR techniques for carbonate lithology reservoirs.
- Microbial cellular factories have a minimal energy demand for the production of the agents required for MEOR.
- MEOR can have a long lasting impact on the reservoir, potentially improving oil recovery over an extended period.

Fig. Different EOR Technique cost estimation [9]




## VIII. LIMITATIONS OF MEOR:

Despite the benefits provided by MEOR, it comes with a handful of challenges which are as follows [8]:

- Injectivity is lost as a result of microbial plugging of the wellbore. To avoid wellbore plugging, some measures needs to be implemented. These measures include filtration prior to injection, avoid biopolymers production, and minimize the microbial adsorption to rock surface by using dormant cell forms, spores, or ultra-micro-bacteria.
- Isolation of microbial strains, adaptable to the extreme reservoir conditions of pH, temperatures, pressure and salinity [6].
- Optimization of the desired in-situ metabolic activity due to the effect of variables such as pH, temperature, salinity, and pressure for any in-situ MEOR operation.
- Limited knowledge about the mechanism for the recovery of oil by microorganisms and the existence of anoxic indigenous microbial ecosystems.
- Corrosion of topside equipment and down-hole piping due to aerobic microbial activities.

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## IX. CONCLUSION:

MEOR emerges as a highly promising and environmentally sustainable method in the realm of oil recovery processes. The use of microorganisms to alter the properties of the reservoir, mobilize trapped oil, and improve sweep efficiency presents a viable alternative to conventional EOR methods. MEOR offer advantages such as cost-effectiveness, minimal environmental impact, good recovery, longevity and applicability to a wide range of reservoir types. However, challenges such as optimizing microbial activities and understanding the complex interactions of microorganism within the reservoir must be addressed to facilitate its widespread industrial adoption. Continued research and field trials are of utmost importance in order to further authenticate the effectiveness of MEOR, enhance its strategies for implementation, and establish comprehensive guidelines for its execution. As the oil industry explores sustainable solutions, MEOR arises as a viable and economically competitive option, holding promise for future implementation in field-scale operations.

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